Restoration of Coral Reef Habitats within the National Park System

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Introduction

The National Park Service (NPS) has long been involved in resource restoration activities designed to enhance the recovery rate of injured terrestrial resources. When injury to natural resources occurs, rapid restoration and recovery is important, both to other resources dependent on the injured resource and to the public who utilize the resource. Restoration actions may reduce cumulative impacts to these stressed systems, speed the recovery of ecosystem function, and minimize loss of dependent organisms.

Coral reefs are often vulnerable to human-caused injury. Coral reefs occur in relatively shallow water, are utilized by the boating public, and are often located near navigation and shipping channels. Injuries from wayward shipping vessels, recreational boat groundings, anchors, sport divers, and fishing gear often compound the effect of other reef stresses and create a need for resource managers to restore the injured resource. Biscayne National Park, Dry Tortugas National Park, Virgin Islands National Park and other coral reef parks in the Pacific have all suffered reef injury incidents caused by grounded vessels. Many vessel groundings result in massive injuries to the reef ecosystem; this then requires mitigative actions to facilitate ecological recovery.

NPS Interdisciplinary Team

To help address the issue of coral reef ecosystem restoration at Biscayne and other national parks, the NPS Natural Resource Program Center, in conjunction with Biscayne National Park and Marine Resources, Inc., have formed a Coral Reef Ecosystem Interdisciplinary Restoration Team. This team is reviewing past coral reef and seagrass restoration actions, compiling available scientific literature on restoration techniques, and developing a guidance document that can be used to address coral reef ecosystem injuries and restoration within the park.

Challenges of Coral Reef Restoration

Ocean environments, particularly coral reef ecosystems, present special challenges to those wanting to mitigate human-caused injuries to natural resources and undertake restoration actions. The primary challenges of coral reef restoration include:

- *Coral reefs support a dense and diverse biological community and are ecologically complex.* Macro-organisms injured or disturbed by even a minor incident of small spatial extent can number as many as several thousands (Glynn 1976; Connell 1978; Gulko 1998). Replacements for macro-organisms impacted during an injury event are extremely difficult to obtain, and natural recruitment and regrowth can require decades or longer to occur (Salvat 1987). In the highly competitive and ecologically complex reef ecosystem, the natural balance of organisms present is also often important (Connell 1976; Glynn 1976). Organisms selected for transplanting or repair, if not placed carefully and with natural processes in mind, can gain an unnatural advantage, prevent recruitment of other organisms, and eventually result in permanently altered communities.

- *Coral reefs occur in high-energy environments*. Ocean surge, wave action, and currents are continuous and often relentless in their effects on restoration attempts. This necessitates utilization of creative technical approaches.
- *Coral reefs have many fragile and/or site-specific microhabitat species.* Coral reefs are highly competitive environments, and many reef organisms have evolved into highly specialized niches (Connell 1976). Loss of habitat or three-dimensional structure due to vessel groundings severely impedes or precludes re-establishment of the pre-injury reef community without recreating the original topographic structure and habitat complexity (Pearson 1981; Miller et al. 1993; Jaap 2000; Hudson and Goodwin 2001).
- *There is a lack of experience and knowledge in successful restoration techniques.* Restoration techniques for coral reef ecosystems are still being developed and evaluated. To deal with high-energy forces within this environment, artificial materials and adhesives have often been used to stabilize reef substrate and to recreate the habitat complexity necessary to re-establish pre-injury species diversity (Miller et al. 1993; Hudson and Goodwin 2001). Some managers feel that the techniques and materials used at some coral reef restoration sites are inappropriate for use in national parks.
- *There is greater difficulty in defining goals*. Injured sites may not be completely restored to their pre-injury condition through mitigative actions. Goals may need to be based on the ability of restoration actions to accelerate habitat recovery following injury incidents. Different agencies and organizations have varying opinions as to what are acceptable mitigative actions and site-specific goals associated with these actions.
- *A long time is needed to evaluate results.* Because of the slow growth and low recruitment potential of coral and many other reef organisms, a long time is needed to fully evaluate results of restoration efforts and the usefulness of the utilized techniques.

The primary challenges facing the team are making the determination as to what restoration actions and techniques are appropriate for national parks and establishing goals and success criteria.

Restoration Goals

One of the most widely accepted definitions of ecosystem restoration in terrestrial environments is: "actions taken to return an impacted site or ecosystem to a close approximation of its condition prior to disturbance" (Cairns 1995). A return to a close approximation of its prior condition is often the goal of terrestrial natural resource restoration efforts in national parks (NPS 1991).

Coral reef ecosystem restoration is more difficult to define. Studies have shown that since coral reefs are such highly complex and ecologically diverse systems, once an injury occurs, the reef cannot be readily "restored" to any close approximation of their pre-impact condition through artificial manipulations (Jaap 2000; Precht et al. 2001; Pinit et al., in press). Most marine biologists acknowledge that natural recovery processes, often in conjunction with artificial manipulation, are necessary to fully restore the ecological condition of an injured site. The rate of recovery to a pre-injury condition can be accelerated through mitigative actions and management intervention by providing physical habitat requirements conducive for natural recovery processes. Therefore, coral reef ecosystem restoration must meet structural and functional goals.

Structural and Functional Goals of Coral Reef Restoration

Injured coral reef ecosystems cannot be entirely reconstructed to a pre-impact condition. Thus, the goal of coral reef restoration activities becomes one of attempting to restore structural and functional components of the site to accelerate natural recovery processes. It is important to achieve the following elements in this process:

- Resiliency to further erosion and loss;
- Self-sustainability in terms of natural processes of repair and recolonization;
- Similarity in appearance to natural reef substrate; and
- Substrate conditions such that, over time, the site will produce a quantity and diversity of organisms similar to surrounding unimpacted areas.

The following goals for coral reef restoration actions have been adopted by others:

- "Actions taken to re-establish a self-sustaining coral reef habitat that, in time, can come close to resembling a natural condition in terms of structure and function." (Key Largo Coral Reef Marine Sanctuary)
- "A proactive program designed to speed recovery of a damaged reef to an endpoint that has aesthetic value and is functional as a coral reef ecosystem." (National Oceanic and Atmospheric Administration Office of Habitat Conservation)

All of these goals have a common element of "taking actions that will enhance natural recovery processes." The amount of management intervention and the type of actions necessary to achieve this type of goal statement vary with the nature and extent of injury sustained, rate of recovery desired, and the degree to which introduction of artificial materials is acceptable.

The NPS Coral Reef Ecosystem Interdisciplinary Restoration Team is working to develop a goal statement that will accommodate a variety of coral reef injuries and provide the latitude to encompass a number of alternative restoration actions.

Injury Categories

To properly analyze and understand the nature of injuries that can occur to a coral reef, it is first necessary to understand the geologic structure and reef growth processes that occur within a coral reef ecosystem. Reef substrate is composed primarily of limestone and is characterized by a reef platform matrix of encrusted and lithified hard-coral skeletons and calcium carbonate rubble. The reef formation is geologically dynamic due to the relative balance of depositional and erosional processes occurring on the structure. Hard corals, calcareous algae, hydrocorals (e.g., fire coral), and bryoans all accrete calcium carbonate onto the reef, building and maintaining the complex structure. Natural erosional processes working to break down the reef matrix include both physical factors, such as currents and storm damage, and biological factors, such as effects of boring sponges, mollusks, polychaetes, and echinoderms. This dynamic balance of on-going, diametrically opposed processes provide structural topographic features of the reef and the highly variable microhabitats within the reef structure. Habitat creation within the reef structure facilitates species diversity due to niche partitioning and biotal zonation. Loss of structural reef components is detrimental to the maintenance of the complex web, which it ultimately supports. Any anthropogenic impact that eliminates reef structure also accelerates habitat degradation and can change the constructional balance of the reef.

Although diving, snorkeling, and other recreational uses of the coral reef ecosystem result in some injury to corals and other reef organisms, the extent and nature of these impacts seldom reach a level that requires mitigation for recovery to occur. Injuries caused by inadvertent contact by divers' fins or standing on corals usually does not impact the reef's geologic structure, and injury to biological organisms usually is isolated and not fatal. This type of injury is considered to be a limited "surficial biological injury." However, when a vessel grounding occurs, impacts to the reef are usually more substantial and may require mitigative actions to decrease recovery time. Vessel grounding impacts can be divided into two categories, surficial and topographic/structural injury, as described below.

Surficial injury. Surficial injury includes that to the biological organisms living on or near the outer surface of the reef and the scraping, grinding, or minor gouging of the reef surface. This category of injury may range from only minor injury of surface biota to much more damaging injuries involving broken coral heads, crushed organisms, and scraping of the reef surface over large geographic areas. The reef's geologic structure remains intact and natural topographic relief (rugosity) at the site remains unaltered. Surficial injuries include the displacement of organisms, overturning and breakage of individual living coral heads and other benthic organisms, and/or burial of living organisms from fragmented material.

Surficial injury impact assessments are two-dimensional (length x width of surface area impacted). Restoration may require removal of loose or grated material to ensure that organisms are not buried and adjacent areas are not impacted from loose material washed around by ocean currents and wave action. If impacts are significant, recovery time can often be greatly reduced through mitigative actions that restore living biological organisms to the site. Restoration actions enhance the recovery of ecosystem function, as well as improve the aesthetic appearance of the site.

Topographic/structural injury. Because coral reefs are geologically composed of a hard outer shell with an interior of unconsolidated sand, shell, and coral fragments, vessel groundings involving heavy ships can cause injury to the reef's geological structural integrity. In this category of injury, the reef matrix is cracked or penetrated and/or major portions of the reef's topographic relief have been altered.

This type of injury destabilizes the reef's surface and makes the reef vulnerable to the erosional processes of ocean currents. Studies have shown that once this occurs, recovery is not likely without mitigative actions to stabilize the site (Miller et al. 1993; Jaap 2000; Hudson and Goodwin 2001). Lack of management intervention following the incident will often result in a continued degradation and enlargement of the impacted site over time. Such impacts can be significant and continue for decades. Stabilization of the site is mandatory even if no other actions are taken. This category of injury usually occurs with vessels over 30 feet in length and usually involves widespread injury and destruction of surface biota in conjunction with loss of reef topographic complexity.

With topographic/structural injury, the impact assessment requires three-dimensional analyses (surface length x width x vertical relief). If topographic height or structural complexity has been lost due to the grounding incident, restoration of the original reef form and structural complexity through mitigative actions may be crucial to recovery. Many organisms within the coral reef community are highly sensitive to water depth, currents, and light levels. All of these factors are changed when topographic relief and structural complexity are altered. If not restored through mitigative actions, natural processes will likely change the site into a permanently altered coral community.

Measures of Restoration Success

As with any management action, it is important to thoroughly evaluate restoration goals and determine the relative success of restoration. Actions taken to enhance the recovery of injured coral reefs are primarily directed at regaining the structural and functional characteristics of the site. Evaluation of the relative success should focus on the structural and functional aspects of the restored site. Structural and functional parameters to be considered for monitoring include, but are not limited to, the following:

Structural:

- Morphological/topographic form of the site—does it resemble the pre-injury habitat or a reference site?

- Stability and structural integrity of restored topography.
- Similarity of abundance and diversity of flora and fauna to the natural unimpacted reef or reference site.

Functional:

- Ichthyofauna—does it resemble that of uninjured reef areas?
- Biological recruitment rates.
- Epibiotal colonization.
- Biological community structure (percent cover, density, and relative abundance).
- Stability, attachment status, and relative health of reattached organisms.

Monitoring a select list of parameters should provide the information necessary to evaluate the relative success of the restoration actions in promoting ecological recovery. Resource recovery will ultimately depend on successful biological recruitment, survival, and development to withstand natural perturbations and provide structural and biological three-dimensional relief that closely resembles that of the pre-injury habitat. Restoration is a process to correct an artificially altered resource and should be applied to prevent the loss and degradation of that resource.

Conclusions

1. Techniques and success of methods for coral reef ecosystem restoration are still being evaluated.
2. Goals of restoration actions need to be stated in terms of re-establishing structure and function to the damaged site.
3. Two factors should be of primary concern when evaluating coral reef damage from vessel groundings or anchoring: (a) extent of penetration and fracturing of the reef's hard outer surface, which may result in further erosion; and (b) loss of reef topographic relief and structural complexity that may have existed at the site before the injury occurred. These two factors will largely govern the extent of geologic stabilization and structural restoration that needs to be implemented to achieve ecological function and processes that will lead to pre-impact, near-natural conditions.
4. Management intervention involving site stabilization and reconstruction of geologic topographic structure is usually necessary whenever either of the two forms of impact mentioned above have occurred.
5. Restoration actions at sites not involving the above two factors may be limited to loose substrate removal and/or biological mitigation for recovery to occur within decadal time frames.
6. Transplanting of biological organisms to impacted sites can serve to greatly improve aesthetic appearances and help accelerate overall site recovery.

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